Key Attributes To Consider When Choosing High Performance Probes

NOT ALL OSCILLOSCOPE PROBES ARE CREATED EQUAL

Product Planner / Keysight Technologies

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KEYSIGHT TECHNOLOGIES

Agenda

- Probe bandwidth
  - Bandwidth definition
  - How much bandwidth are you getting?
  - Probe tip may be the weakest link
  - Probe AC correction technique
- Probe loading
  - RC vs RCRC
- Probe noise
- Probe input range
- Probing at extreme temperature environments

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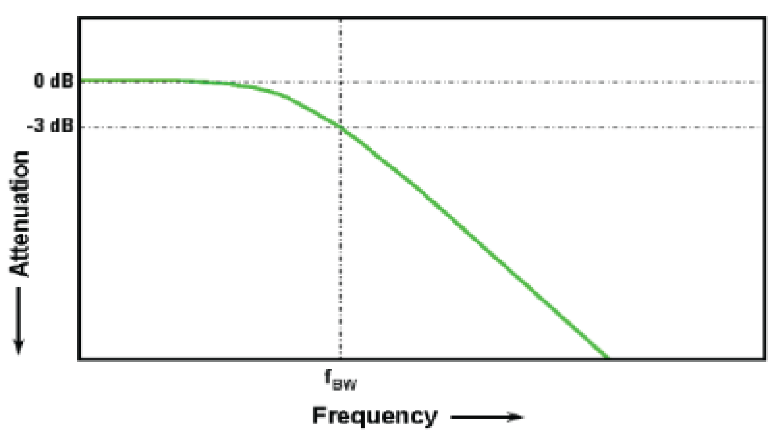
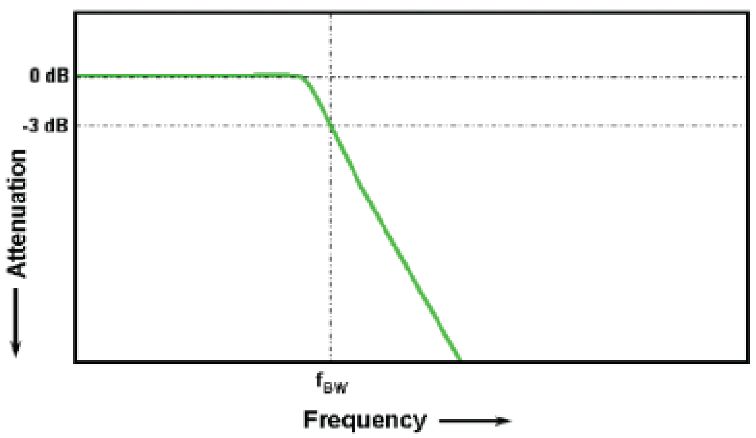
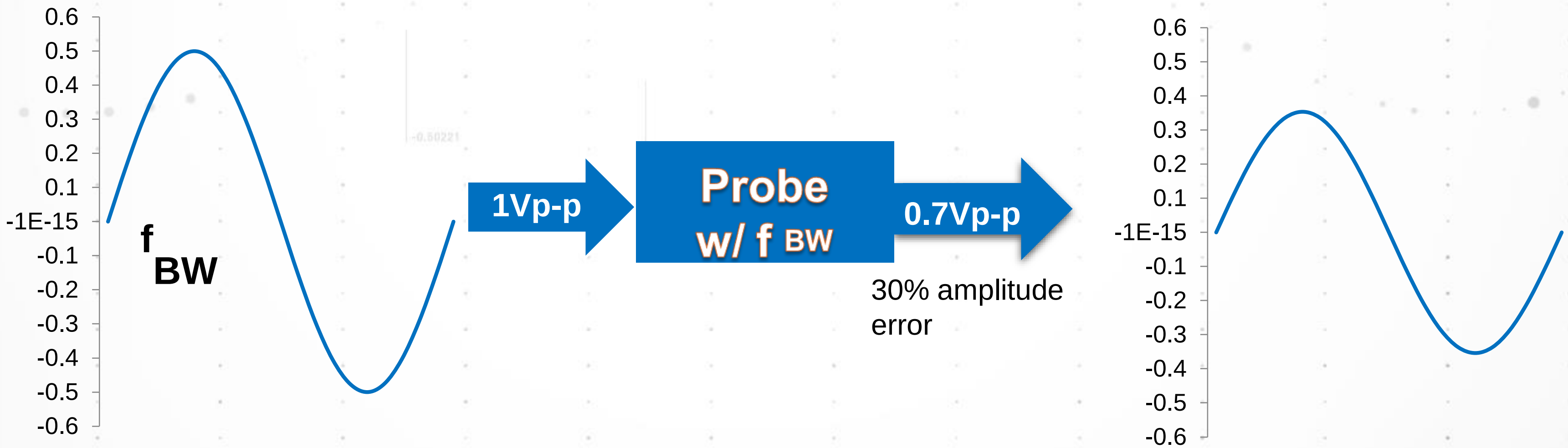
Probe Bandwidth



Gaussian frequency response (≤1 GHz)



Brick wall frequency response or maximally flat frequency response (>1 GHz)



Probe bandwidth is specified at the frequency at which a sinusoidal input signal is attenuated by 3dB or to 70.7% of the signal's true amplitude.

Probe Bandwidth

Required Probe BW =

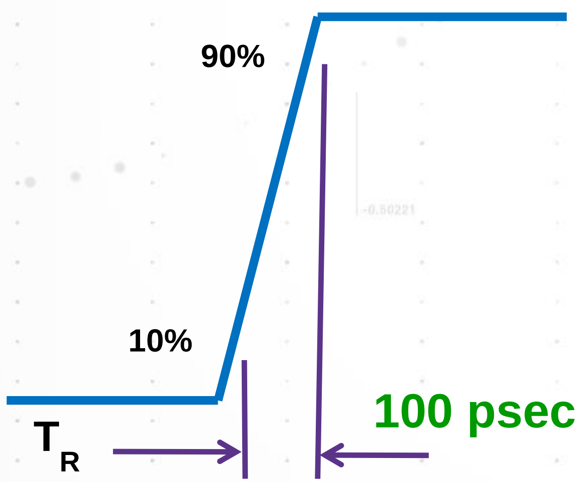
3x – 5x the signal BW
(Gaussian)

1.2x – 1.4x the signal BW
(Brickwall)

Signal BW*T_R = 0.35
(Gaussuan)

Signal BW*T_R = 0.43
(Brickwall)

where T_R being 10%-90%



Example: Signal 100 psec Edge Speed

$T_{R\text{-Signal}}$ = 100 psec (Rise/fall time of your fastest signal)

Signal BW_{signal} = 0.43/100 psec
= 4.3 GHz

Required Probe BW =
1.2x to 1.4x the signal BW =
5.1 GHz – 6 GHz

How much of system BW are you getting?

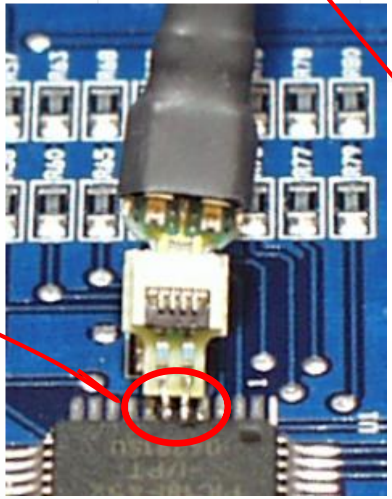
Does this legacy system bandwidth equation still hold true?

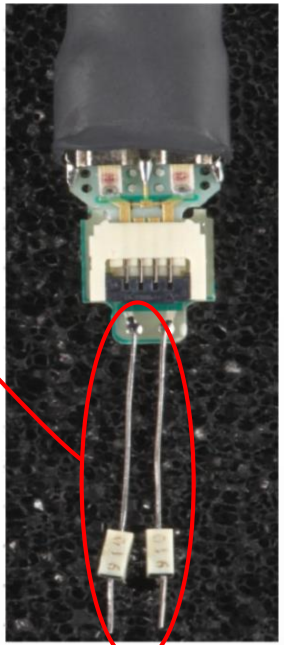
$$\cancel{\boldsymbol{System\ bandwidth} = 1 \Big/ \sqrt{\frac{1}{\boldsymbol{scopeBW}^2} + \frac{1}{\boldsymbol{probeBW}^2}}}$$

- The equation is not very applicable to much of modern oscilloscope and probing system these days.
- This equation only applies for components that have very little overshoot/undershoot and ringing in the step response.
- This equation specifically does not apply to the high performance scope/probe system with Brickwall responses.
- **The “slowest” component in the chain (scope + probe + probe accessories) determines the system BW.**

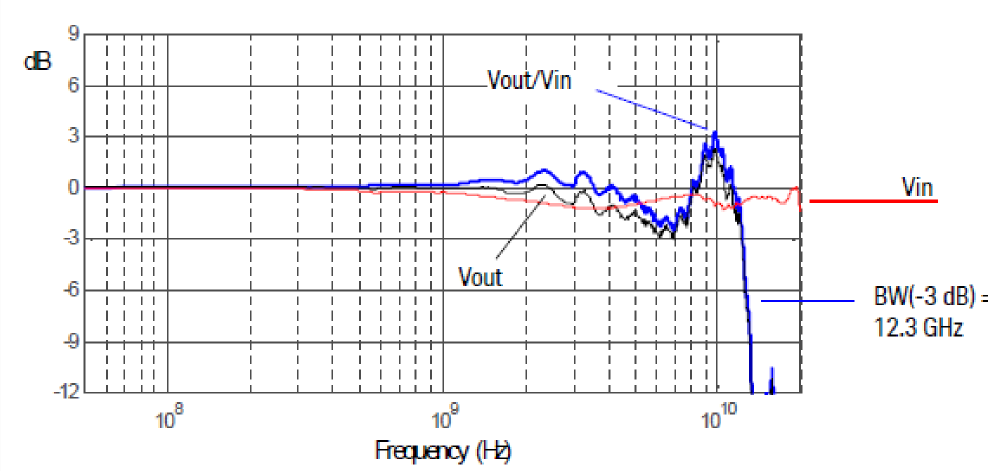
Effects of varying lead length/span

N5425B ZIF head with	Lead length	Separation between legs	Bandwidth
N5426A ZIF tip	2 mm	0 deg	12.3 GHz
N5451A Long-wired ZIF tip	7 mm	0 deg	9.9 GHz
	7 mm	60 deg	4.4 GHz
	11 mm	0 deg	5 GHz
	11 mm	60 deg	3.3 GHz

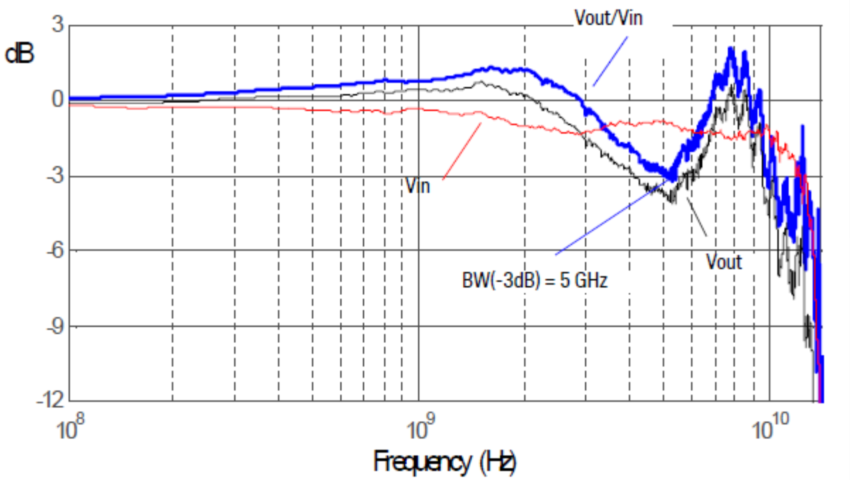




Probe accessories can greatly affect the overall performance

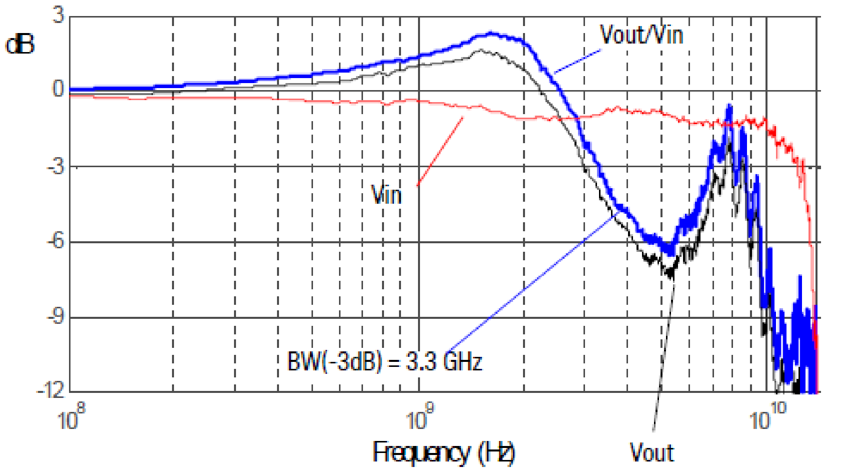


2mm ZIF tip, 0 deg separation



11mm ZIF tip, 0 deg separation

Longer input lead wire and wide loop area significantly impact probe response and bandwidth.

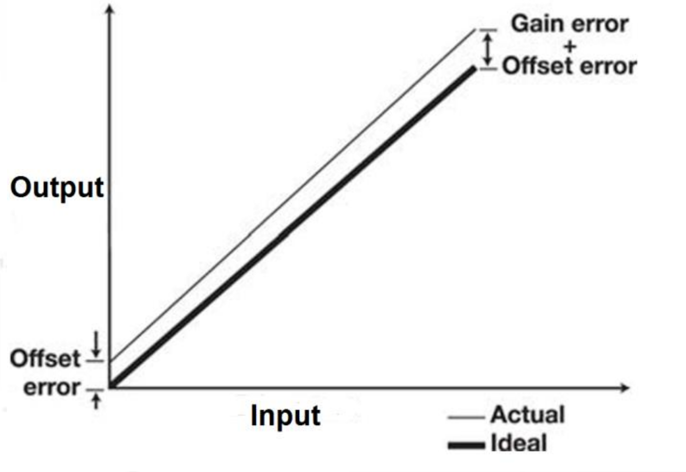


11mm ZIF tip, 60 deg separation

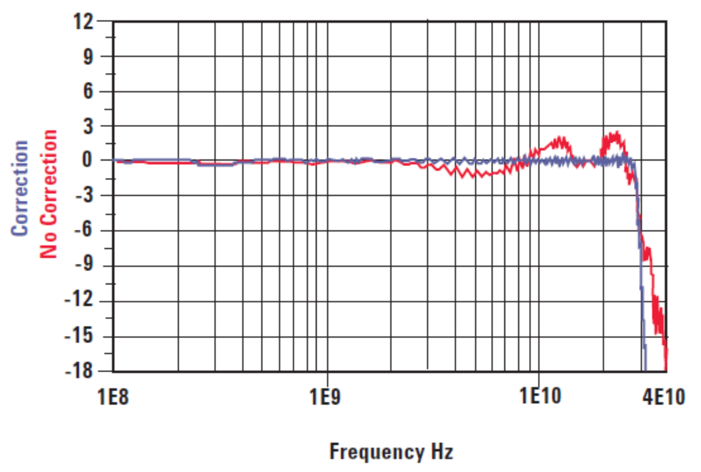
Truths about Probe Calibration

- Most conventional probes come with DC gain and offset calibration.

  DC Offset cal : To make f(0) = 0
  for Vout = f(Vin)
  DC Gain cal : Y = aX + b
  AC : relies on the probe's hardware response, no cal

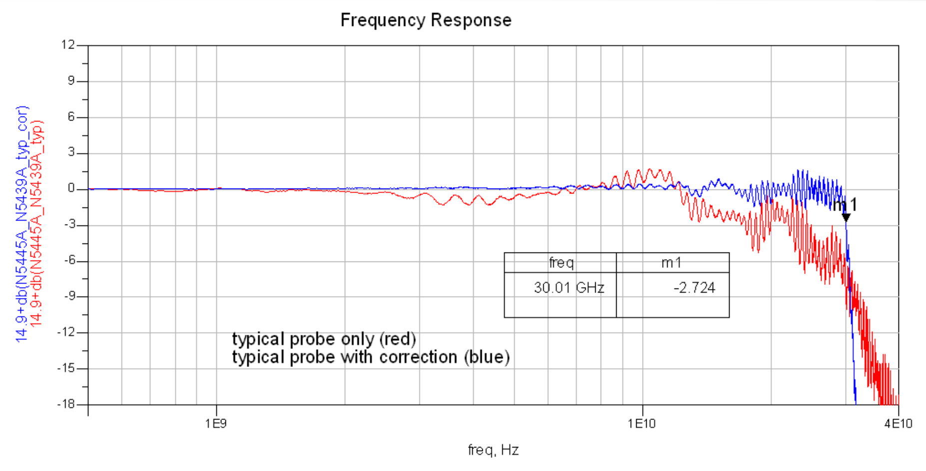


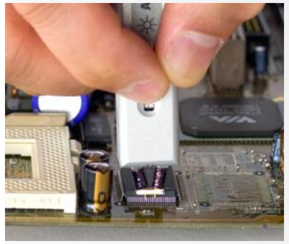
- High performance probes with scopes do DSP correction for probe amp and head to achieve better performance and higher accuracy.



DSP corrections improve accuracy but…

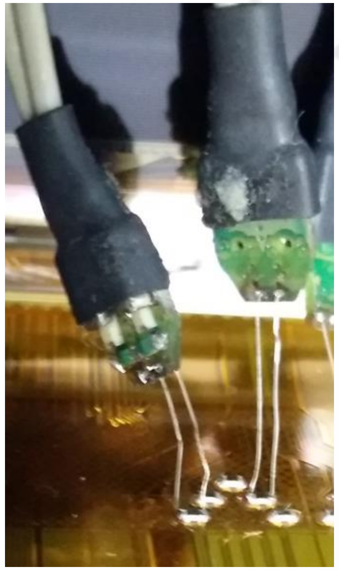
- Some high-end probes offer measured S parameters for a step-up in the accuracy of probes.

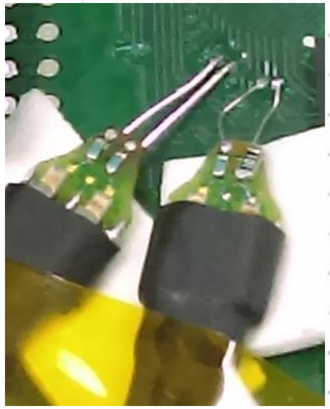




- However, other factors such as the variation in probe tip configuration such as
  - tip length,
  - tip span,
  - arrangement of wires,
  - partial damage, and
  - probe orientation to DUT

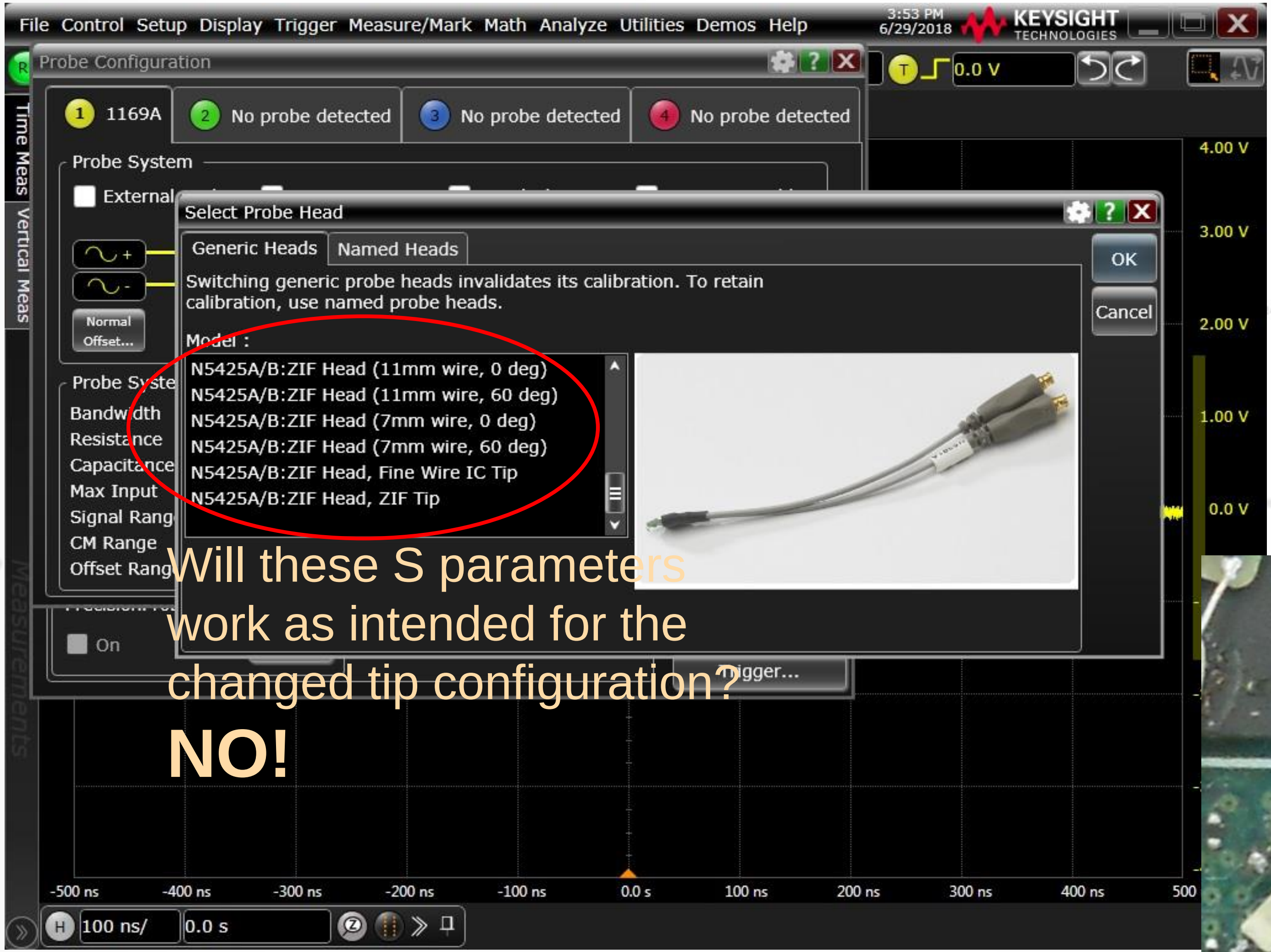
 can still affect probe response.





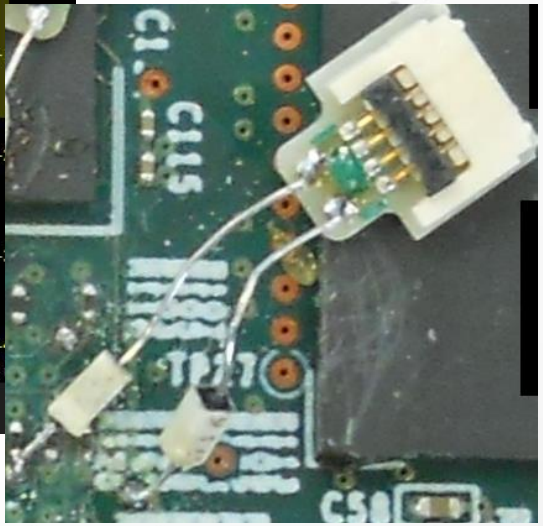
KEYSIGHT TECHNOLOGIES

What if the DSP correction doesn't cover your probe tip configuration?



Will these S parameters work as intended for the changed tip configuration?

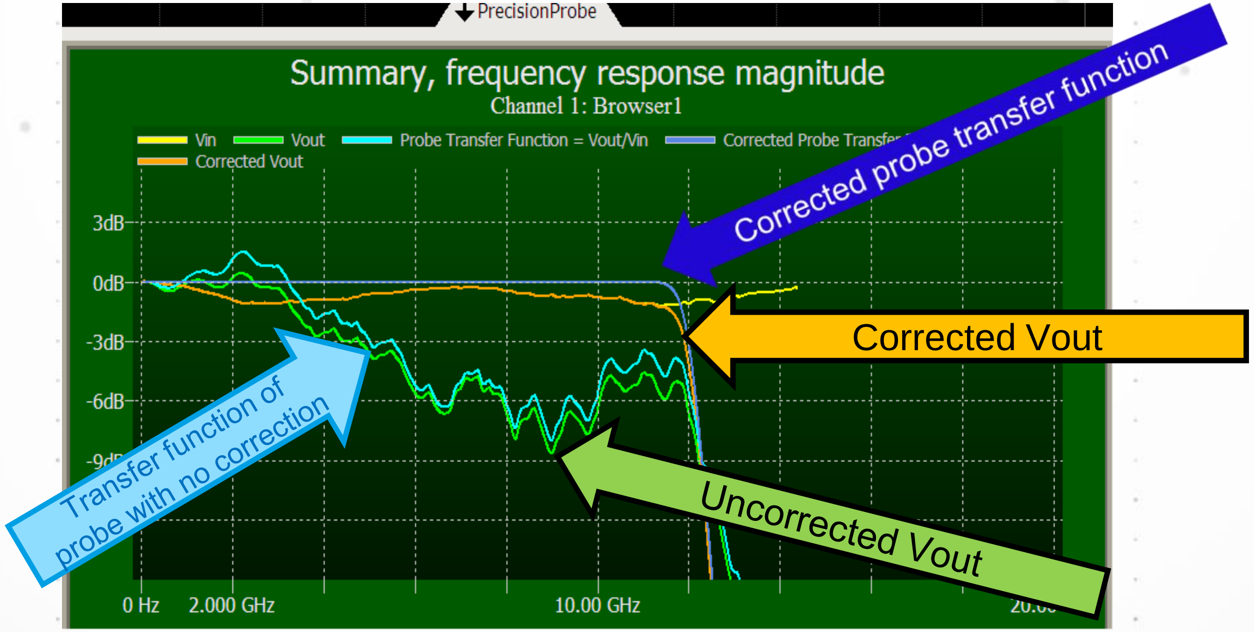
NO!



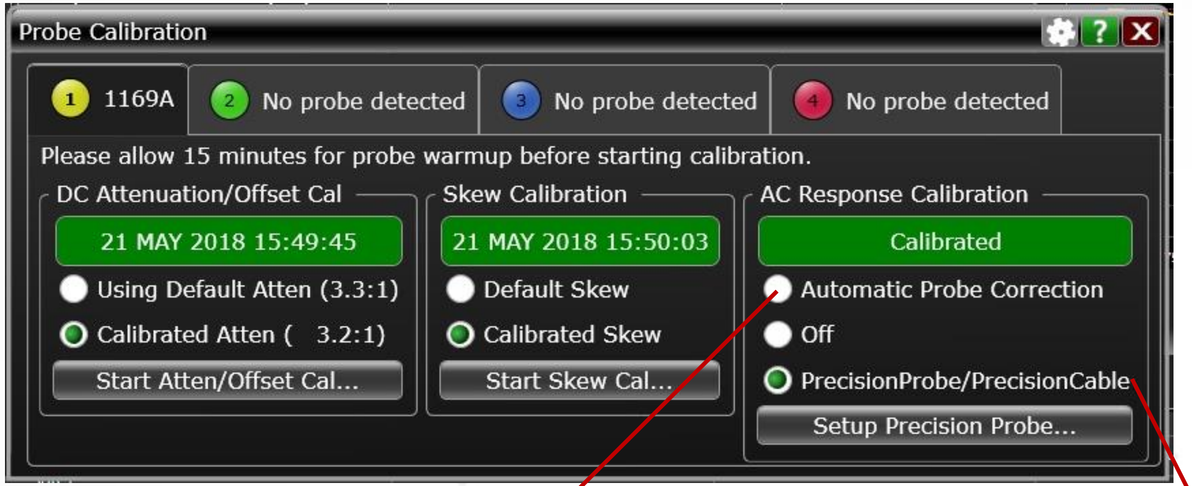
More Advanced Probe Correction Method Using PrecisionProbe

- The ideal way to ensure the best accuracy for a probe is to perform a calibration of its response ***<u>in the configuration that it will be used</u>*** before critical measurements are made.

- The PrecisionProbe application uses the fast calibration step signal and a high quality probe fixture with cables to accurately measure and correct for the response of any probe.



AC Calibration Options



Automatic Probe Correction: uses factory generated S parameters for InfiniiMax probe amp and head.

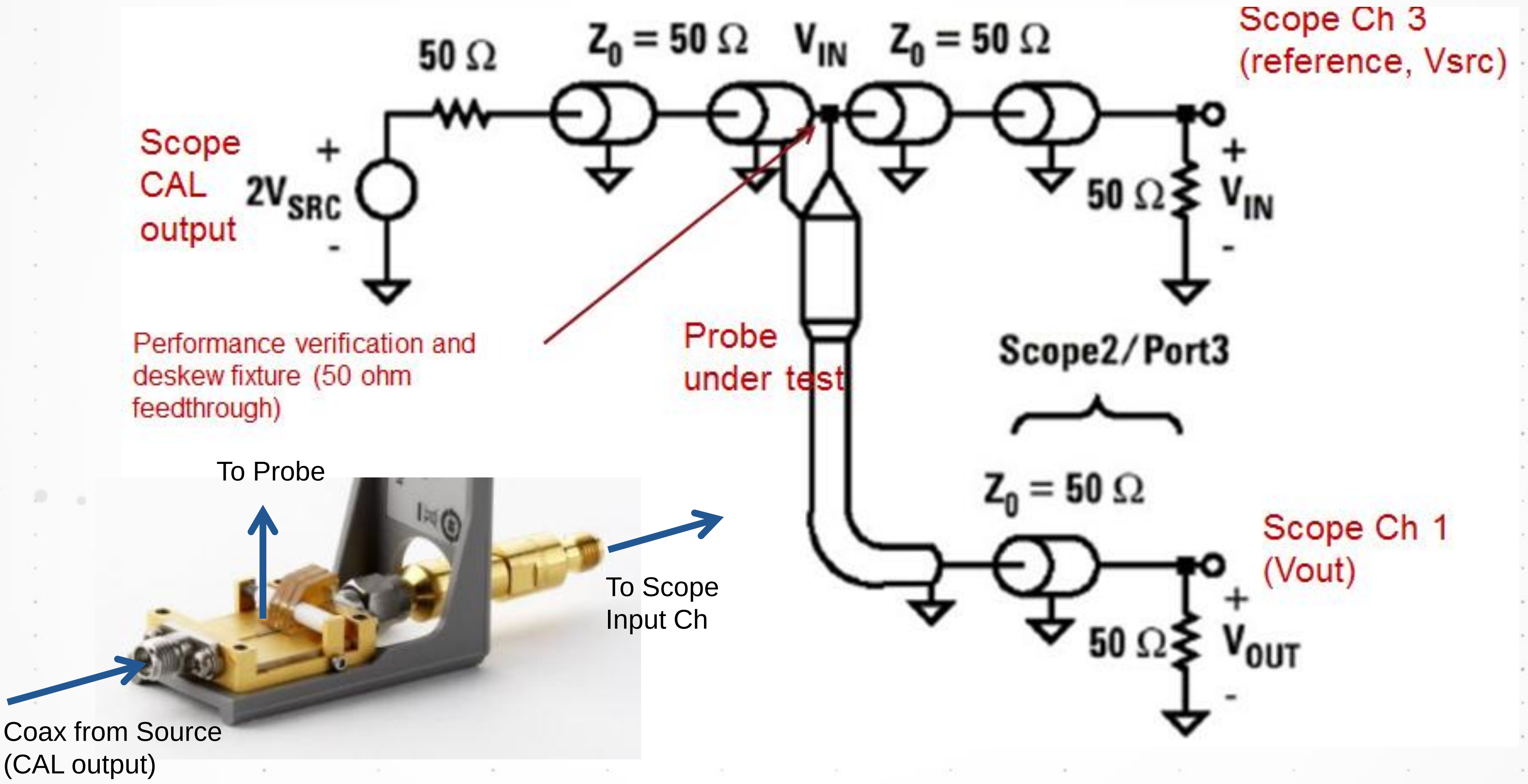
It is important to choose the right probe head and accessories in the probe head menu to get appropriate probe head correction.

PrecisionProbe/PrecisionCable: uses the measured probe/cable response obtained from the PrecisionProbe cal.

PP cal takes care of AC correction from the probe amp to the tip end.

KEYSIGHT TECHNOLOGIES

Test setup to perform PrecisionProbe testing



25Ω source impedance

How it works

1. Apply a very fast cal step signal to the scope input thru a low loss fixture and cable.
2. Create a frequency response of the step using the scope's built-in math and FFT (Vsrc – before probe connection)
3. With the probe connected, repeat the above process for Vin (signal as loaded by probe) and Vout (output of the probe).
4. By relating the response of the Vsrc, Vout and Vin, we create a new transfer function (Vout/Vin or Vout/Vsrc).
5. Infiniium software creates an inverse filter to create a nice flat response to improve the measurement accuracy.

Bandwidth boosted 1169B using PrecisionProbe

- **The bandwidth of 1169B (12 GHz InfiniiMax probe) + N5381B solder-in head can be boosted to 15 GHz with PrecisionProbe without significant noise penalty.**
- Noise penalty at 15 GHz (compared to 12 GHz) is ~20%.

12 GHz – standard 1169B

15 GHz

16 GHz

Bandwidth boosted 1169B + N5381B solder-in head using PrecisionProbe

The rise time at 12 GHz was 47 psec and improved to 39.8 psec for 15 GHz.

At 12 GHz, rise time (10-90%) = 47.1 psec

At 15 GHz BW, rise time (10-90%) = 39.8 psec

At 16 GHz BW, steps look too bursty and noisier

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  - **RC vs RCRC**
- Probe noise
- Probe input range
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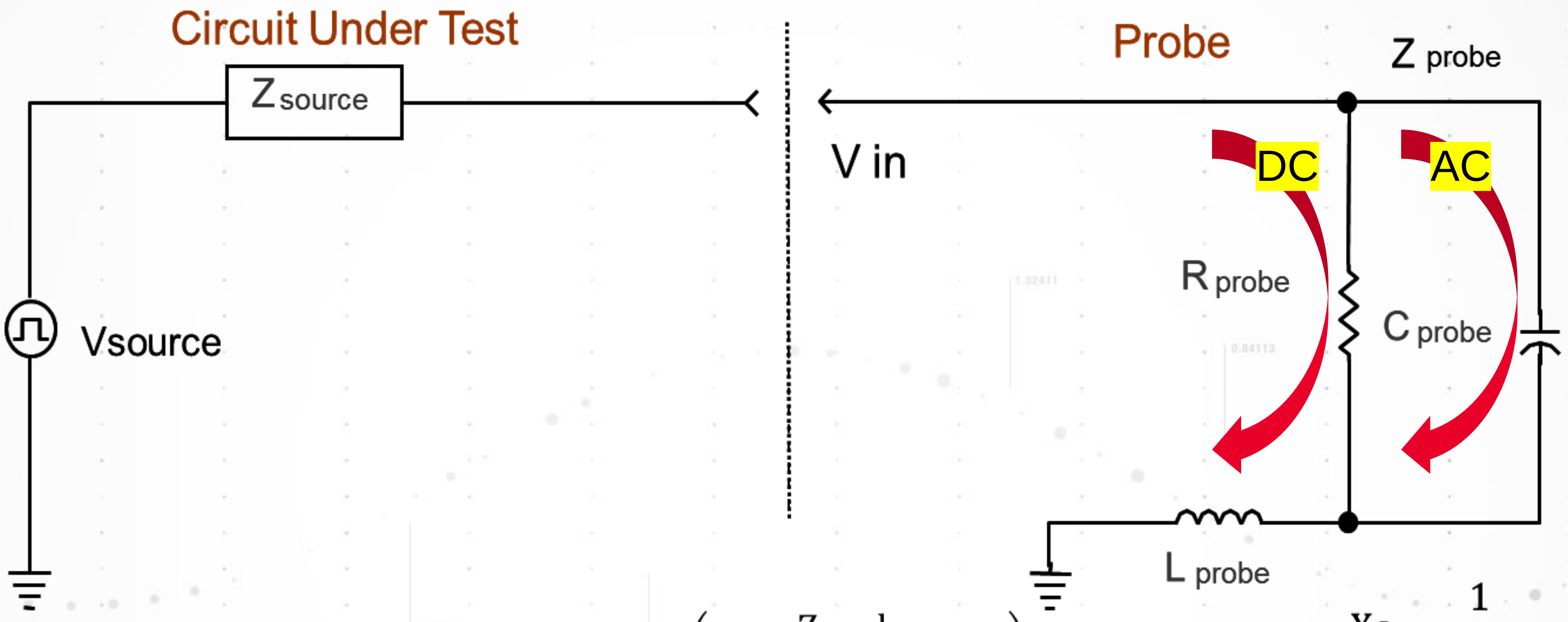
Probe Loading

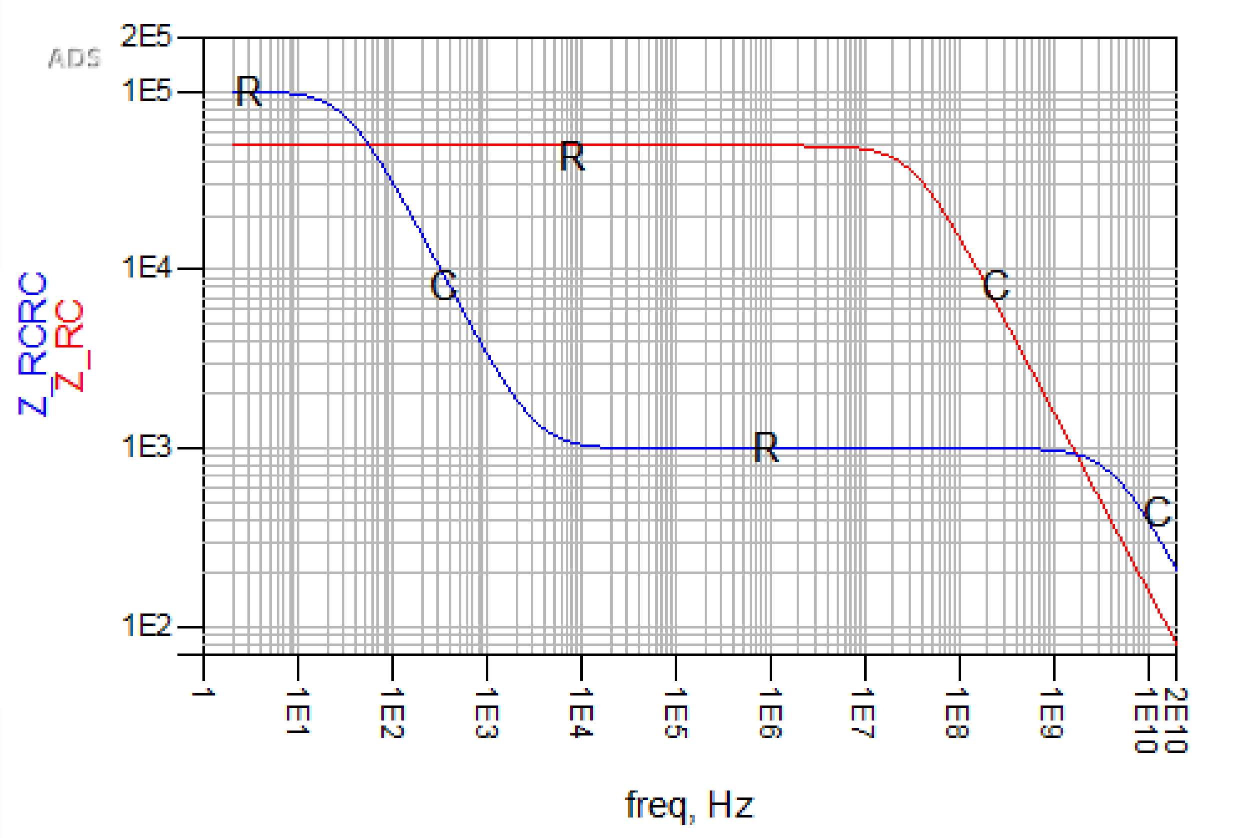


$$Vin = Vsource * \left(\frac{Zprobe}{Zsource + Zprobe}\right)$$

$$Xc = \frac{1}{2\pi fC}$$

- Probe becomes an additional load driven by the signal source.
- Resistive, capacitive and inductive loading effects must be considered.
- Probe can change the operation of the DUT.

Two Common Probe Impedance Profiles

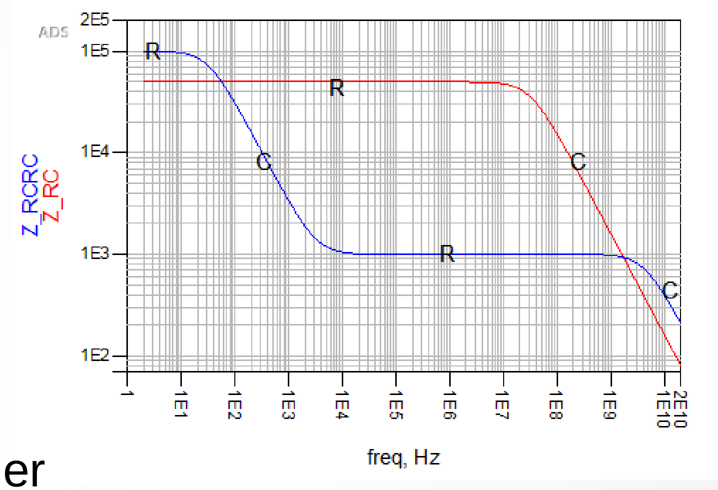


"RC" (red trace): traditional resistance – then capacitance impedance profile

"RCRC" (blue trace): High DC impedance, moderate mid-band impedance

“RC” Probe Impedance Profile

PROS AND CONS



Pros

Traditional probe impedance profile

High R best for probing circuits with a higher source impedance

Best for circuits whose source impedance changes from High Z to Low Z (e.g., bus that transitions in and out of high Z mode)

Cons

Harder to achieve high bandwidth due to multiple components at tip

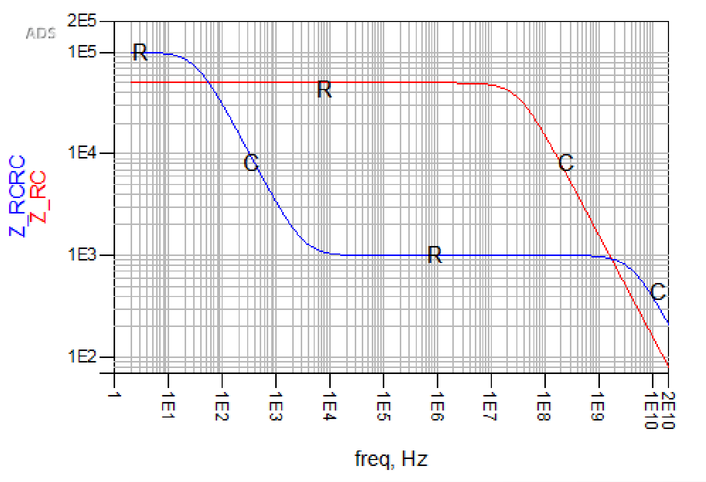
Harder to achieve low noise – doesn’t “steal” as much signal

Hard to minimize capacitance causing “rounding” of the step response

Too much DC loading if R is too low

“RCRC” Probe Impedance Profile

PROS AND CONS



Pros

Better for preserving wave shape

Easier to achieve high bandwidth since less components at tip

Better at achieving low noise (i.e., “steals” more signal

Cons

Not optimal for measuring circuits with high source impedance

Not good for measuring circuits that transition from high Z to low Z (i.e., causes long time constant)

Lower mid-band impedance attenuates amplitude

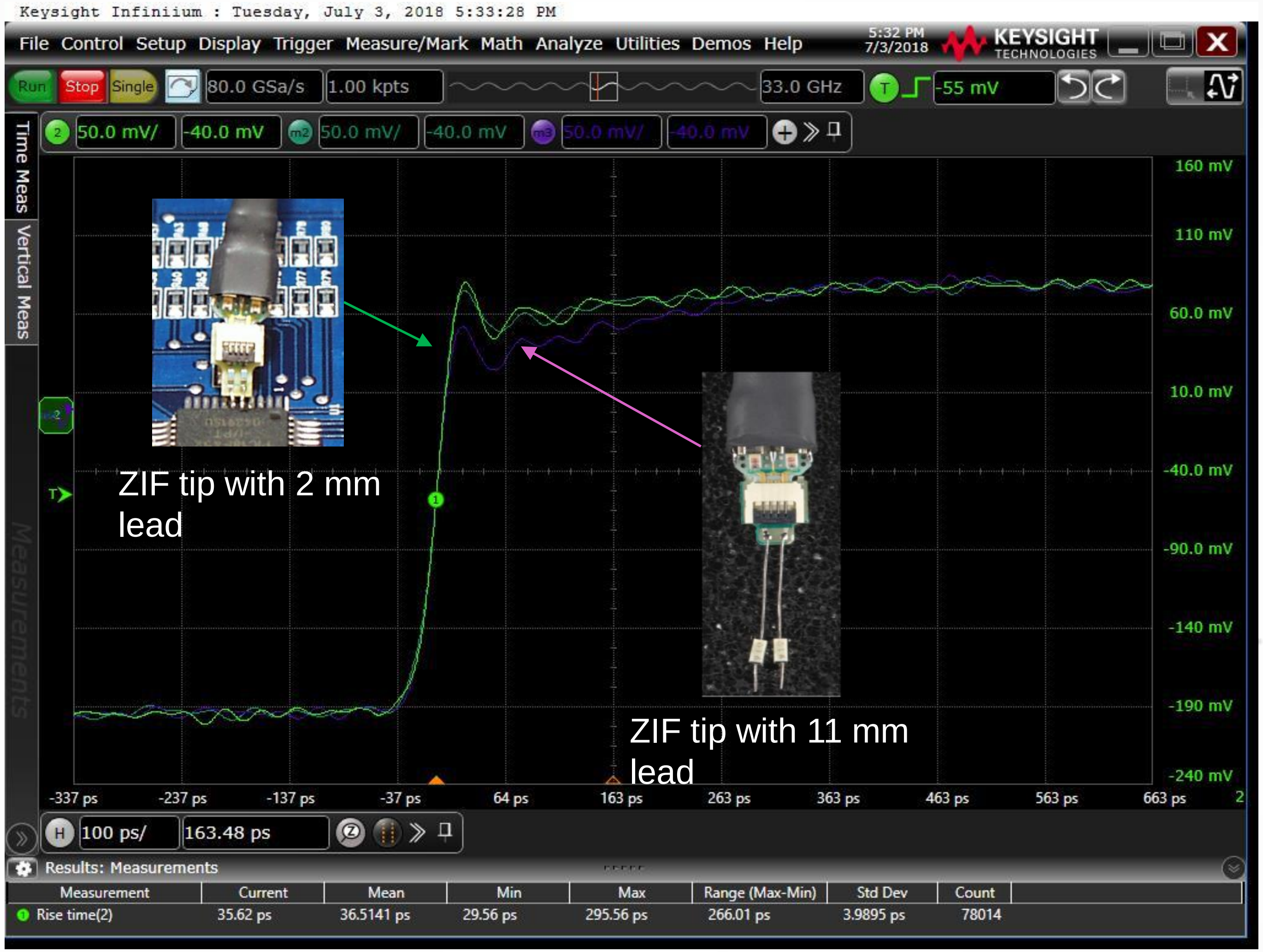
KEYSIGHT TECHNOLOGIES

Probe loading effect in measuring MIPI D-phy

Yellow = Keysight N2832A InfiniiMax III+ 13 GHz probe (RCRC)
Blue = Keysight 1169B InfiniiMax II 12 GHz probe (RC)

RC probe (such as InfiniiMax I/II) is recommended for this application.

Probe loading is impacted by probe tip configuration



Longer input lead wire impact probe's loading characteristics that cannot be compensated!

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Understanding the probe noise specification

- Probe noise is typically quoted in the probe only noise referred to the probe input or ein (equivalent input noise) in mVrms or in noise spectral density, $nV/\sqrt{Hz}$
- You can convert from one quantity to the other by factoring in the bandwidth of the probe.

Features	N280XA InfiniiMax III probe amp		
	450 Ω probe heads	200 Ω probe heads	N5444A 2.92 mm, SMA, 3.5 mm probe head
Input referred noise spectral density	23.9 nV/rt (Hz)	12.0 nV/rt (Hz)	23.9 nV/rt (Hz)

	1169B
Noise referred to input	2.5 mV rms, probe only

KEYSIGHT TECHNOLOGIES

Understanding the probe noise specification

- The ein of a probe is derived by calculating the noise contribution of the probe (or output noise of the probe) by using the square root of the sum of the squares or eon.

$$eon = \sqrt{(noise\ of\ probe\ and\ scope)^2 - (noise\ of\ scope)^2}$$

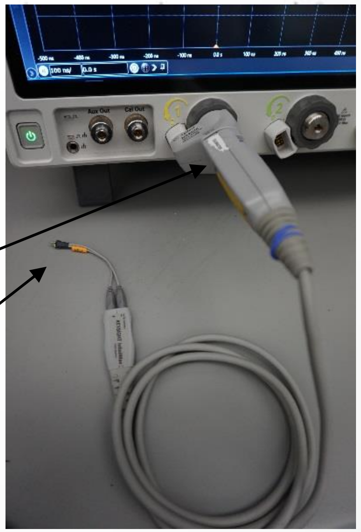
- Now you can calculate the ein of the probe by multiplying eon by the attenuation factor. For example, eon = 250 uVrms with a 10:1 probe, ein would be 2.5 mVrms.

- $Noise\ spectral\ density = ein/\sqrt{probe\ bandwidth}$

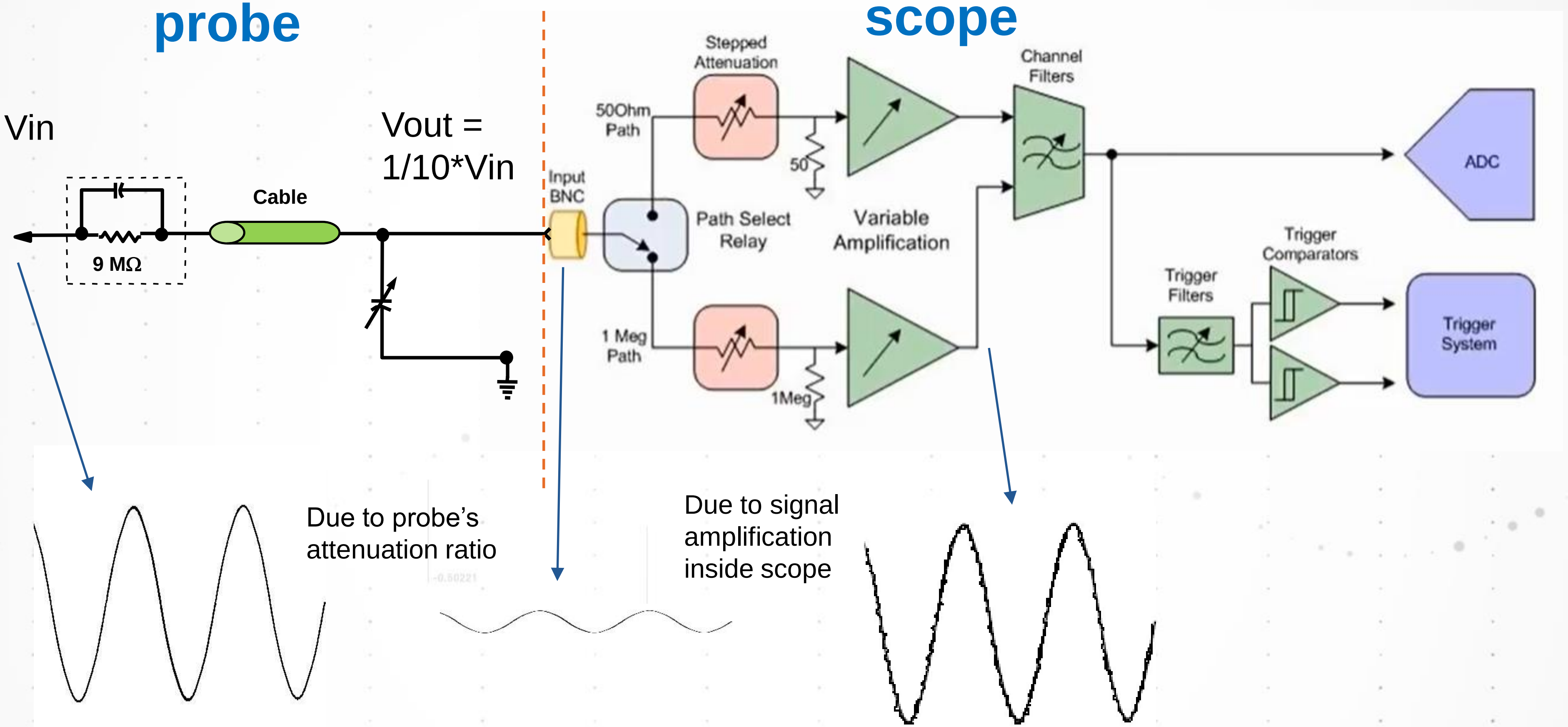
  For 2.5 mVrms ein measured with a 12 GHz probe,
  noise spectral density = 21 $nV/\sqrt{Hz}$

eon

ein = eon * attenuation factor

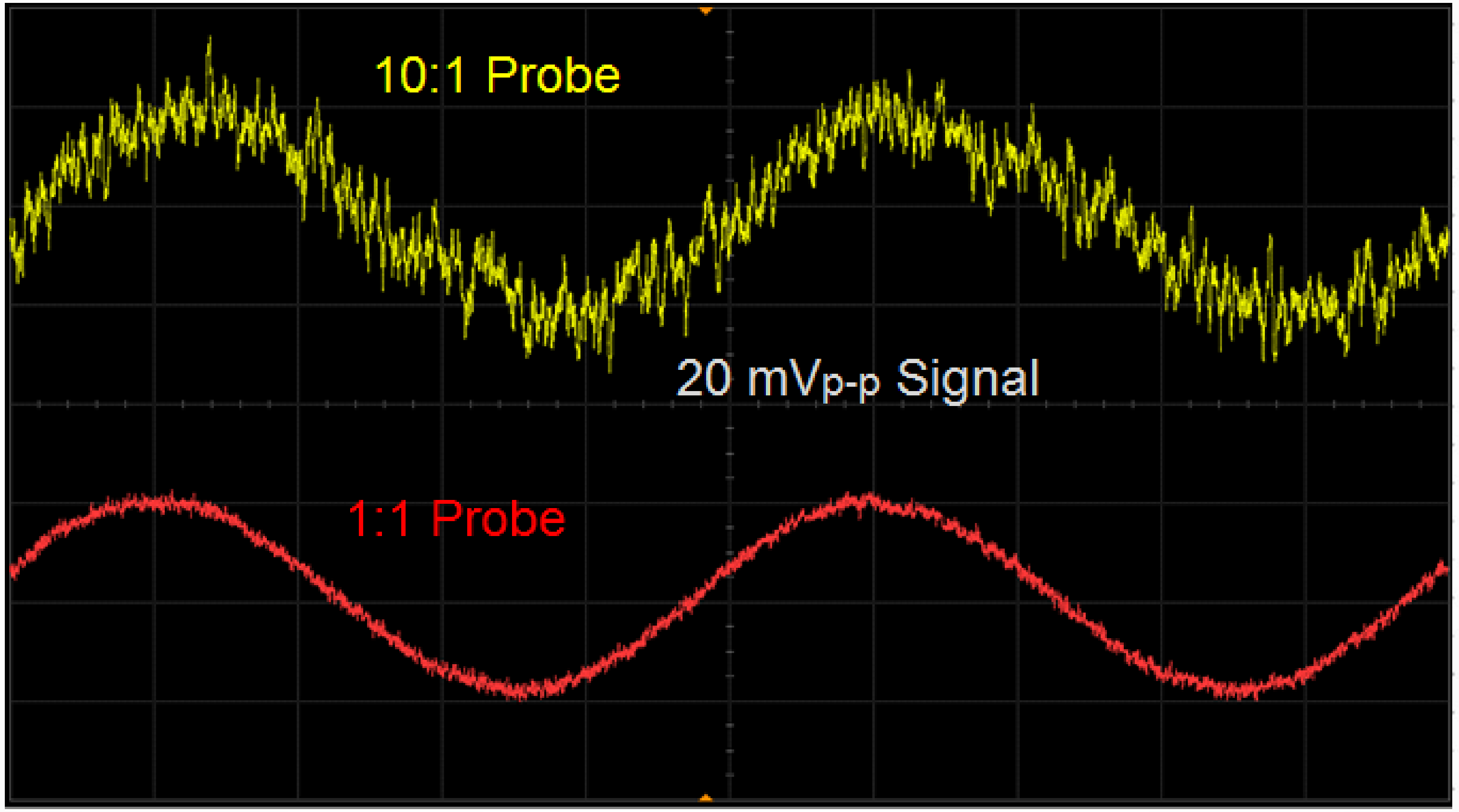


Probe and oscilloscope front-end



- The system noise will increase when the scope increases attenuation to allow a larger max input range.
- It's advantageous to use the most sensitive vertical range (lower V/div) to avoid unnecessary noise magnification.

Lower attenuation ratio leads to higher signal-to-noise ratio



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Probe Input Range Terms

– **For differential probe:**

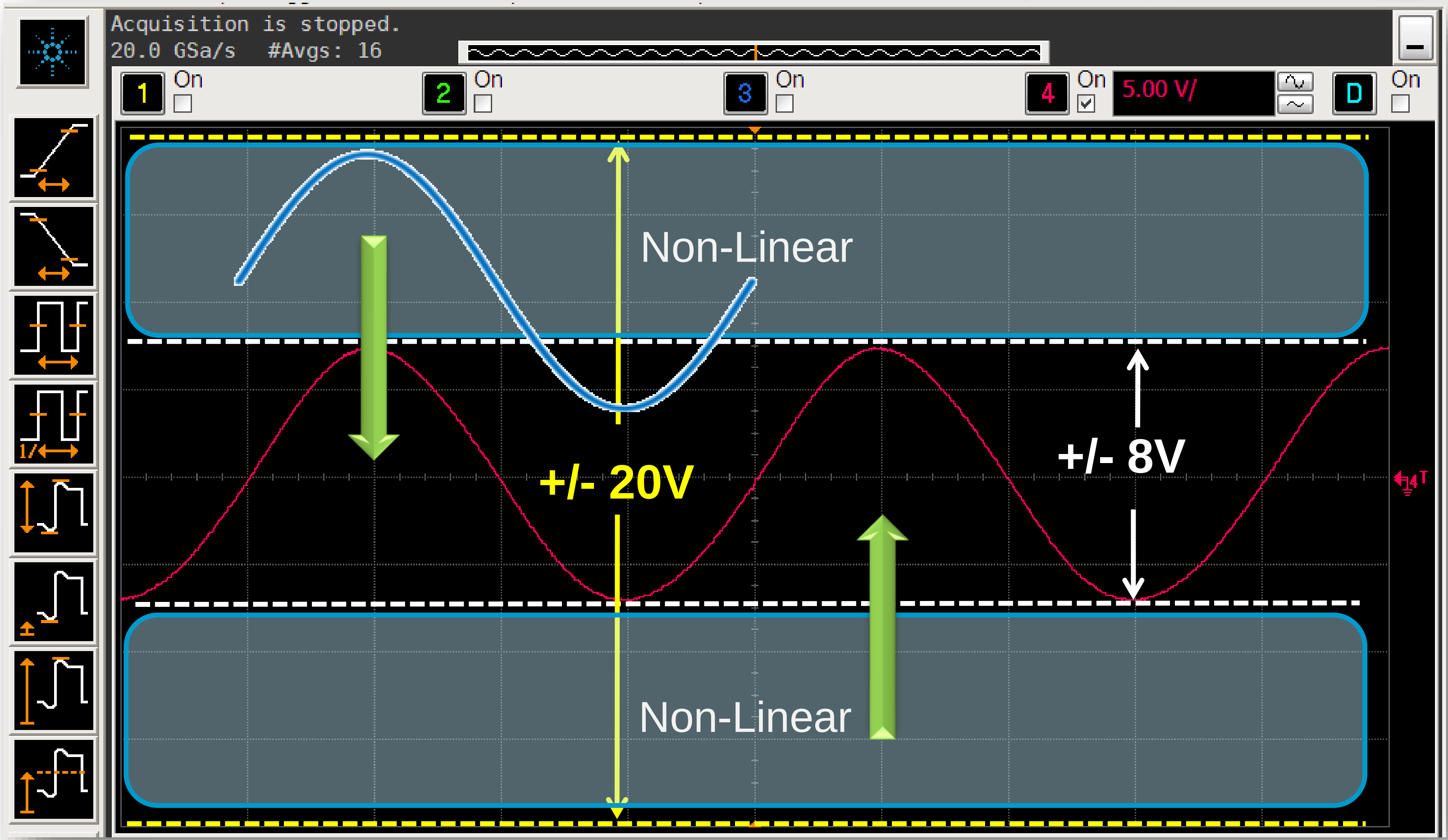
- “Differential input range”, “Dynamic range”
- “Input common mode range”, “Common input voltage range”, “Operation voltage input range”, “Offset compensation range”
- “Offset range (for probing a single-ended signal)”
- Non-destructive input voltage range

– **For single-ended probe:**

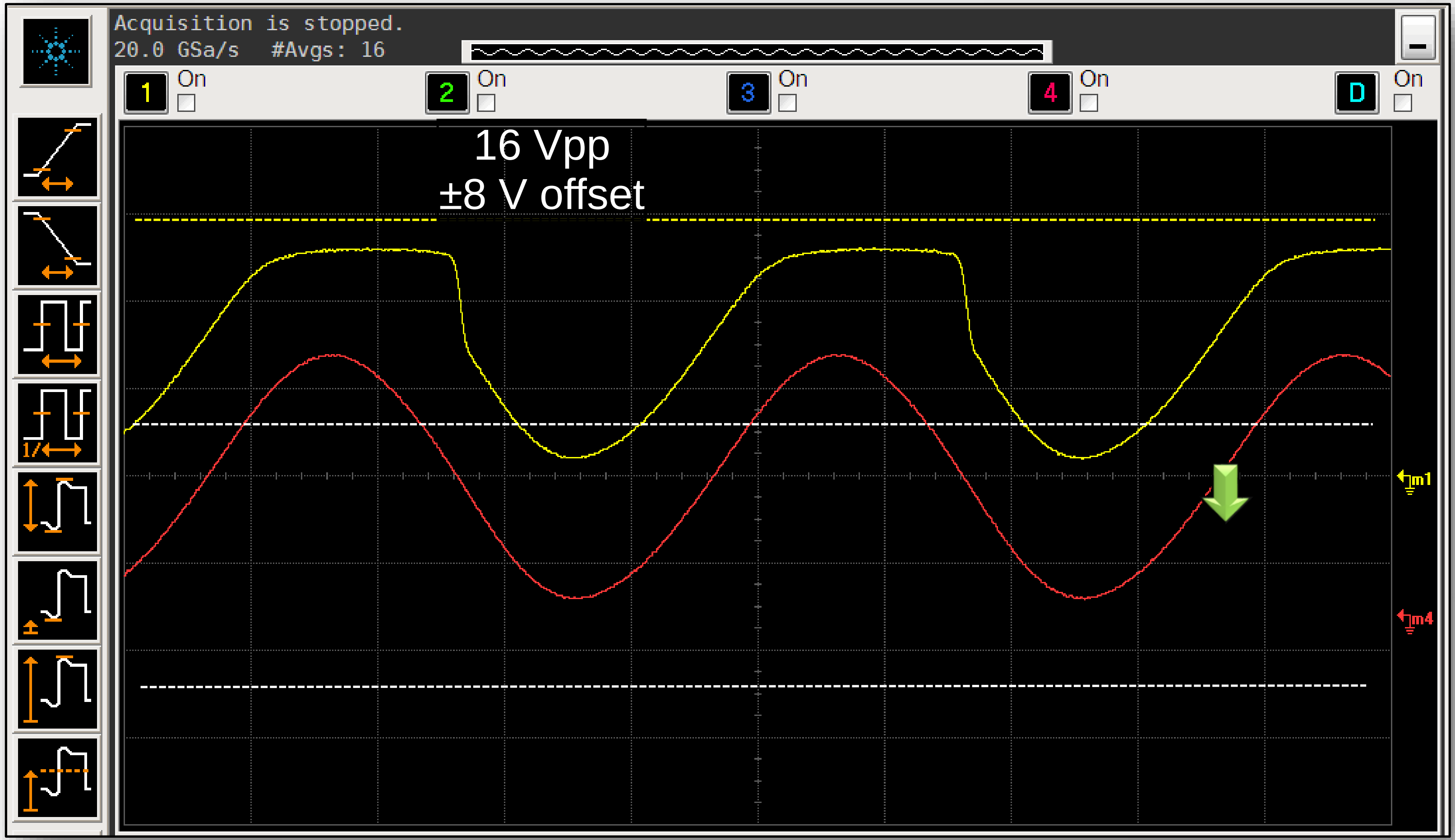
- Input signal range
- Offset voltage range
- Non-destructive input voltage range

SE probe: Offset Range & Dynamic Range

Input Dynamic Range	N2795A: -8V to +8V (DC or Peak AC)
Non-destructive Max Input	N2795A: -20V to +20V
Offset Range	N2795A: +/- 8V



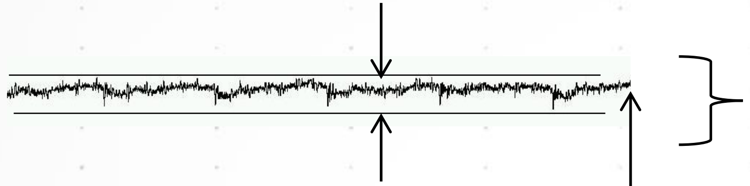
SE probe: Offset Range & Dynamic Range



Why offset range? For the subtraction of the dc component of the input signal so the signal can better utilize the dynamic range of the input.

Probing challenge

Measuring small AC signal riding on top of large DC offset

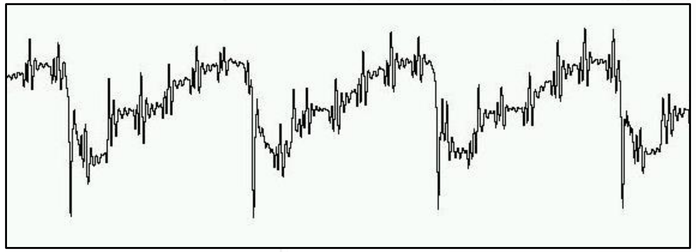


Challenge: Measure small ac signal on top of large dc signal

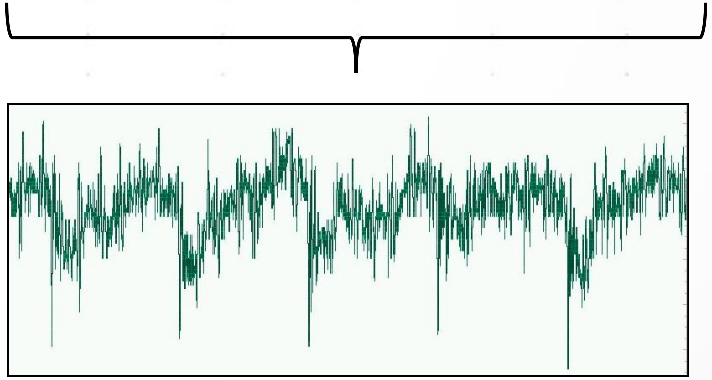
Issues to overcome:

DC

1. How to deal with measurement system noise
2. How to eliminate large DC component and extract the AC signal clearly.



Measurement System Noise (Scope, Probe, Connection…)



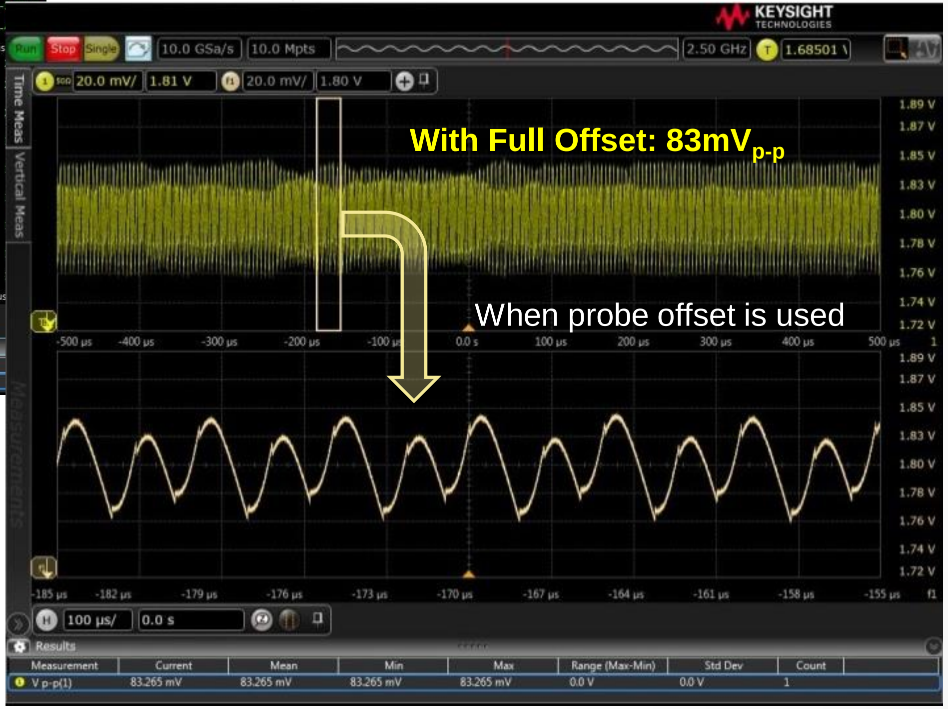
KEYSIGHT TECHNOLOGIES

Power Integrity Measurements

Use probe offset over scope offset

At larger V/div,

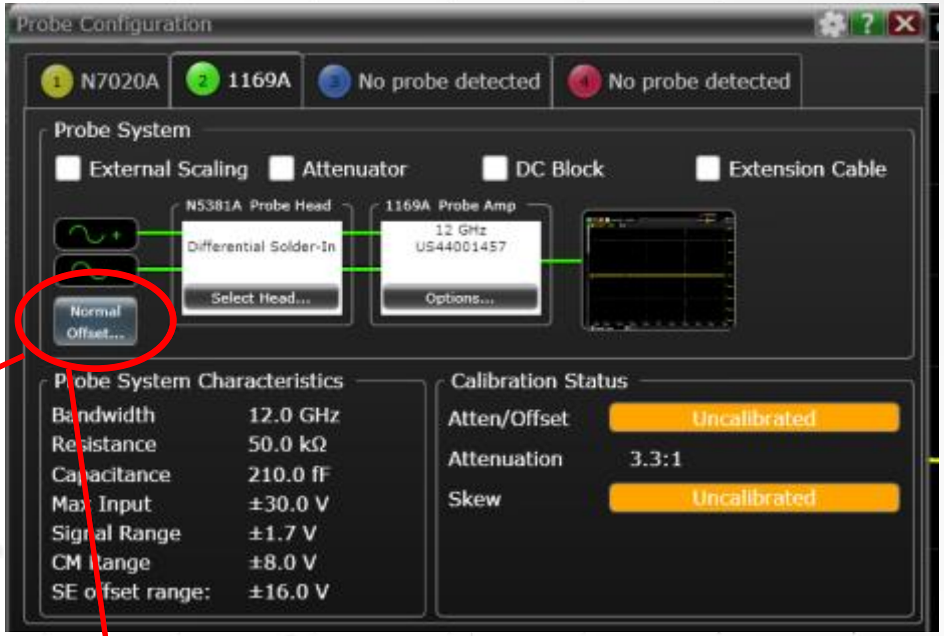
- Sensitivity is decreased
- Scope noise relative to small ac signal is increased.

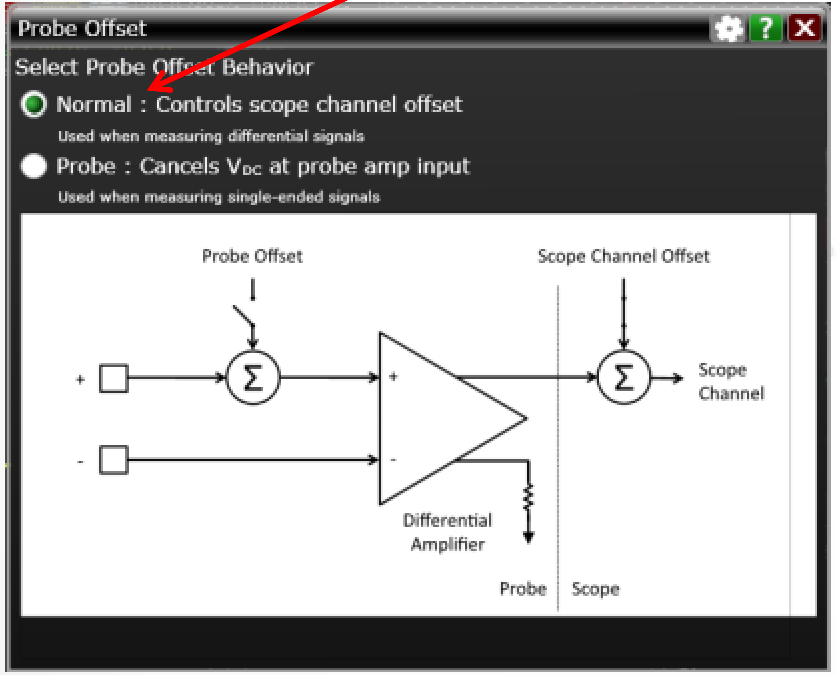


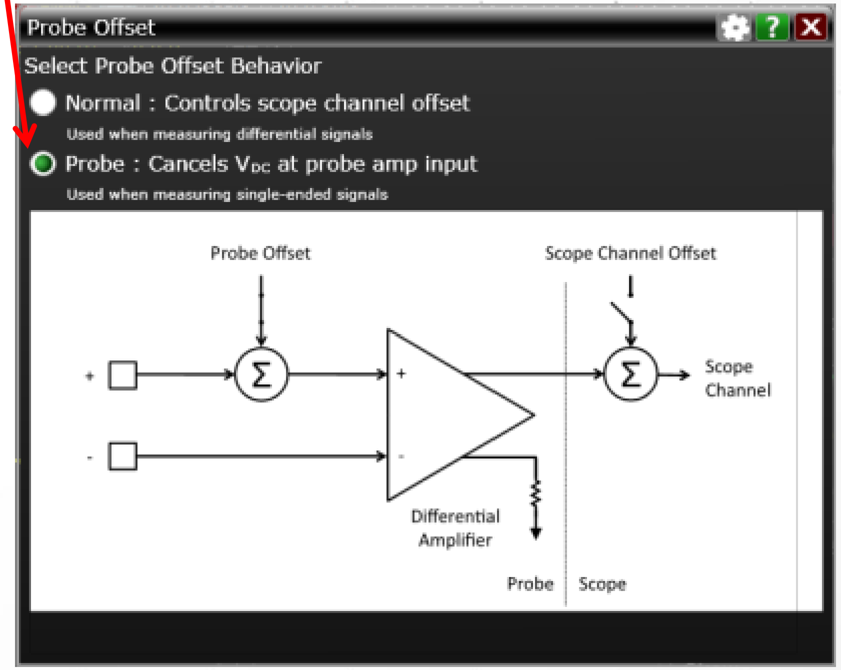
- Scope offset range is vertical scale dependent, but probe offset is not.
- Remove large DC signal using probe offset!

Diff probe: Probe offset vs Scope offset

- Probe offset provides a wider range that can be applied to input signal independent of vertical scale.
- InfiniiMax probe offset ranges
  - Infiniimax I : ±12 V
  - Infiniimax II : ±16 V
  - InfiniiMax III/III+ : ±16 V
- Use probe offset to look at small signal riding on top of big DC signal.



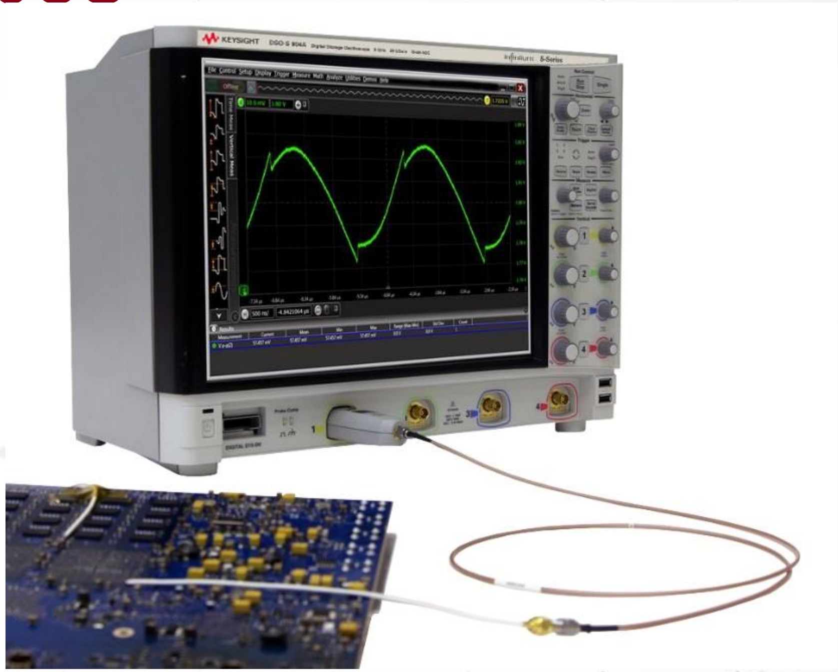


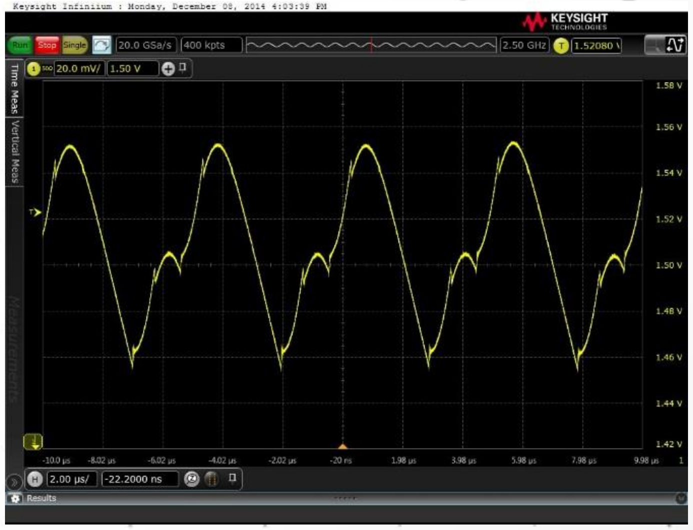


KEYSIGHT TECHNOLOGIES

Keysight Power Rail Probes

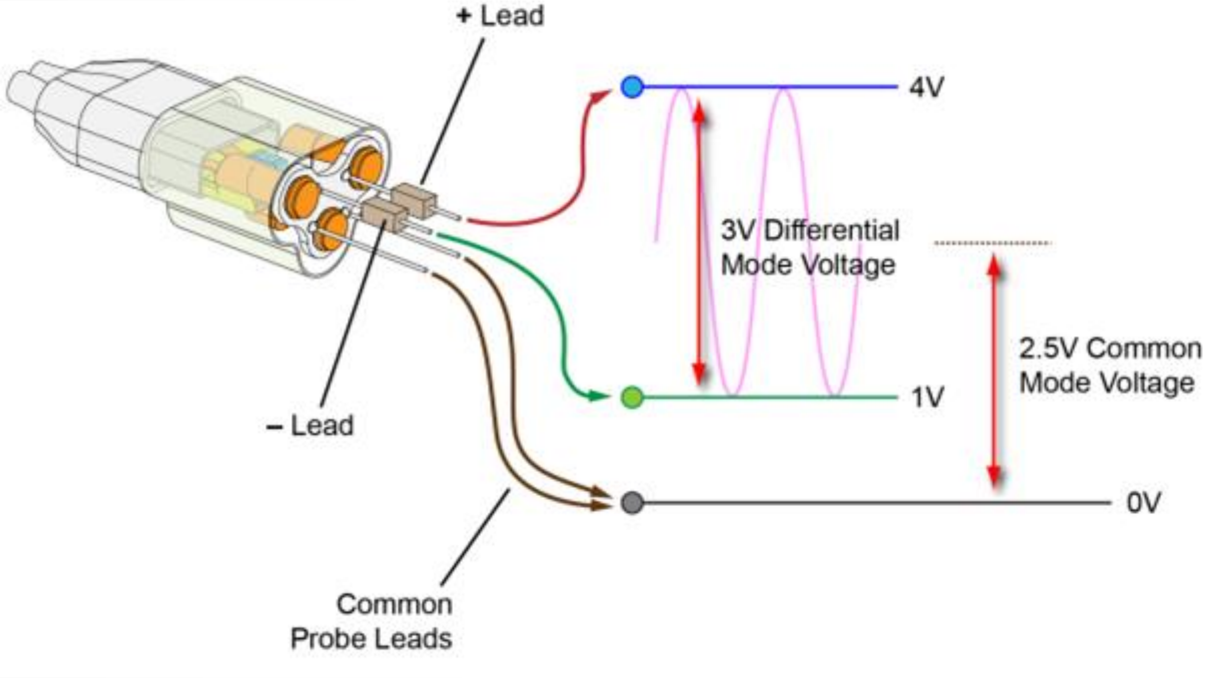
- DC to 2 GHz (N7020A) / DC to 6 GHz (N7024A - NEW) power rail probes for power integrity measurement
- Low attenuation ratio ensures high signal-to-noise ratio
- Large probe offset ranges (+/24V, +/-15V) allow for extracting the signal noise of interest while at maximum scope sensitivity
- Compatible with InfiniiVision and Infiniium scopes





Diff probe: Common mode measurement

InfiniiMode allows convenient measurement of differential, single-ended and common mode signals with a single probe tip without reconnecting the probe from its connection point.



Differential

$$A - B = 4V - 1V = 3V$$

Common Mode

$$\frac{A+B}{2} = \frac{4V + 1V}{2} = 2.5V$$

Single-Ended A

$$A - \text{gnd} = 4V - 0V = 4V$$

Single-Ended B

$$B - \text{gnd} = 1V - 0V = 1V$$

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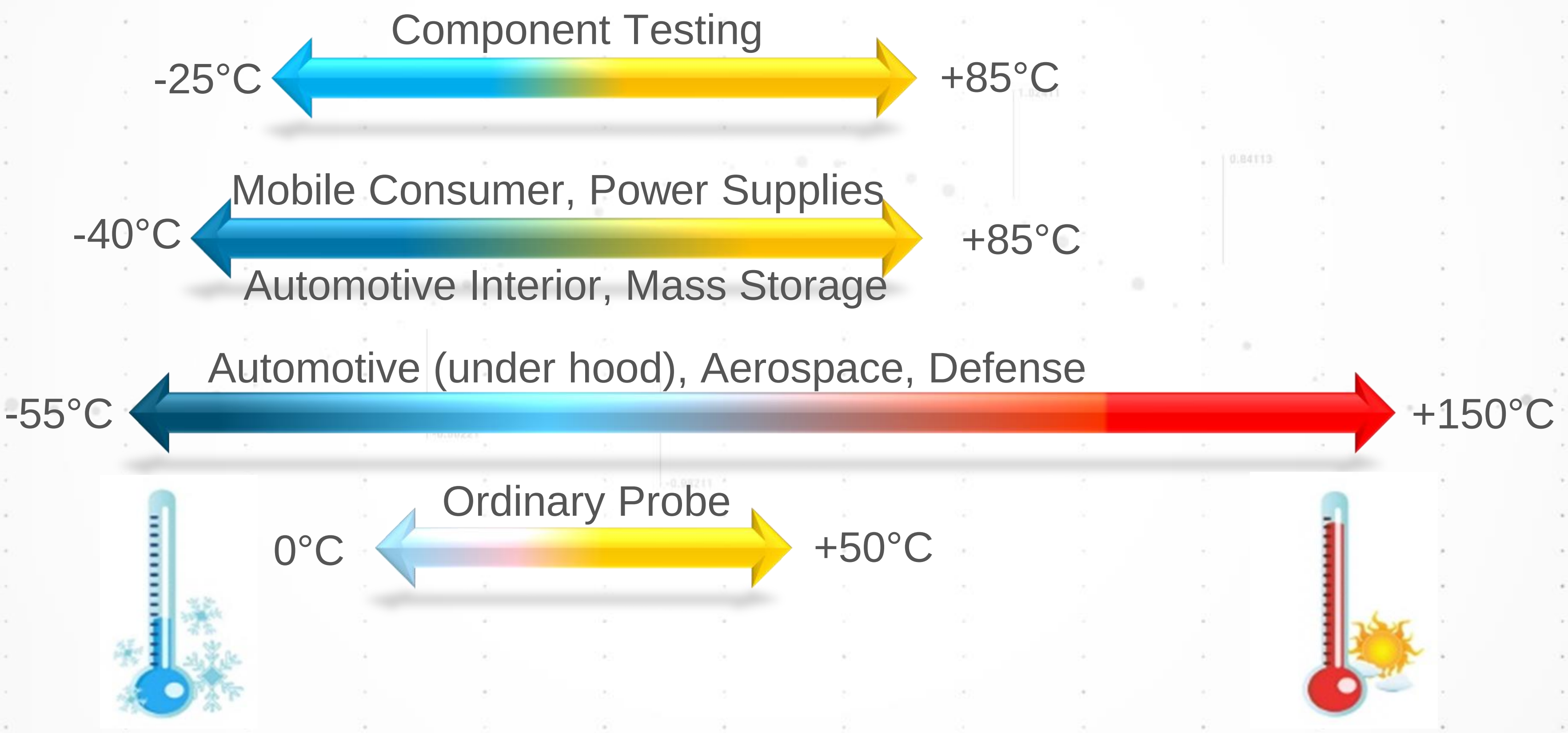
KEYSIGHT TECHNOLOGIES

Oscilloscope Probing in Extreme Temperature

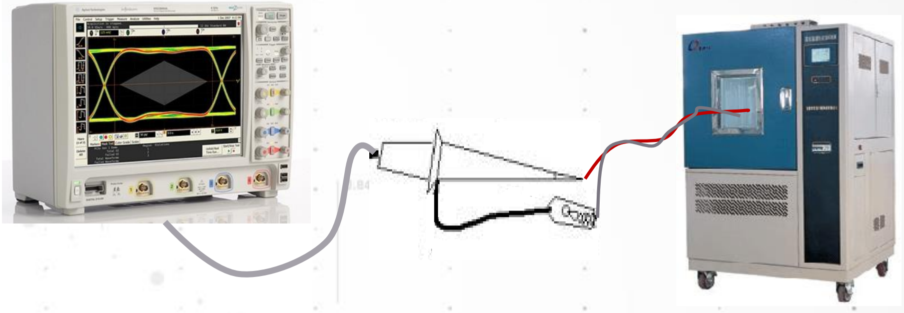
Temperature test ranges and applications



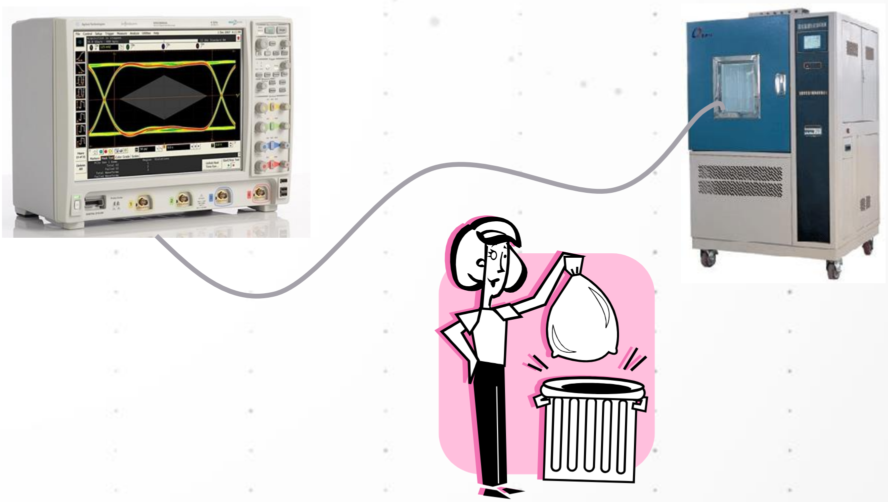
Two most common methods today

Two most common methods today

- **Probe connected to DUT via long extensions**
  - Limited bandwidth and non-flat frequency response
  - Noise couples onto extension wires



- **Probe is placed directly into chamber**
  - Cost of “disposable” probes
  - Probe failures create false readings



Keysight's Extreme Temperature Probing Solution

NEW

N7007A
Single-ended Passive
400 MHz
10MΩ input R
2 m long cable
-40 to +85 °C

N7013A
Probing kit for differential probe
70 MHz
Compatible with N2790A, N2791A, N2792A, and N2818A
70 cm long cable
-40 to +85 °C

N2797A
Single-ended Active
1.5 GHz
1MΩ input R
2 m long cable
-40 to +85 °C

InfiniiMax + N5450B extension cable + probe head
Differential & SE Active
1.5 GHz – 26 GHz
50 kΩ input R
-55 to +150 °C

N2820A/21A High-sensitivity current probe
Current
3 MHz
1.5 GΩ input R
-55 to +150 °C

Keysight offers the broadest selection of extreme-temperature oscilloscope probing solutions. www.keysight.com/find/extreme

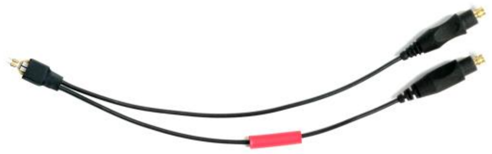
Extended Temperature Probing with InfiniiMax Probe

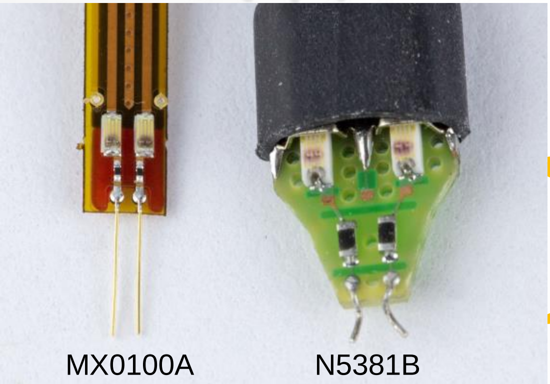
MX0100A : 12 GHz Micro Solder-in Probe Head

- < Half the size of existing solder-in probe heads
- Small, flat and flexible (using flex printed circuit)
- Compatible with any InfiniiMax I/II RC probe amps
- Operating temp range: -55 - +150°C

MX0109A : 26 GHz Solder-in Probe Head

- 26 GHz bandwidth
- Same performance as N2836A
- Compatible with InfiniiMax III/III+ RCRC probe amp
- Operating temp range: -55 - +150°C





New probe heads are designed to withstand

- -55°C dwell, >1000 hours
- +150°C dwell, >1000 hours
- -55 °C to 150 °C cycles, 1000 cycles minimum per JEDEC JESD22-A104 revision E

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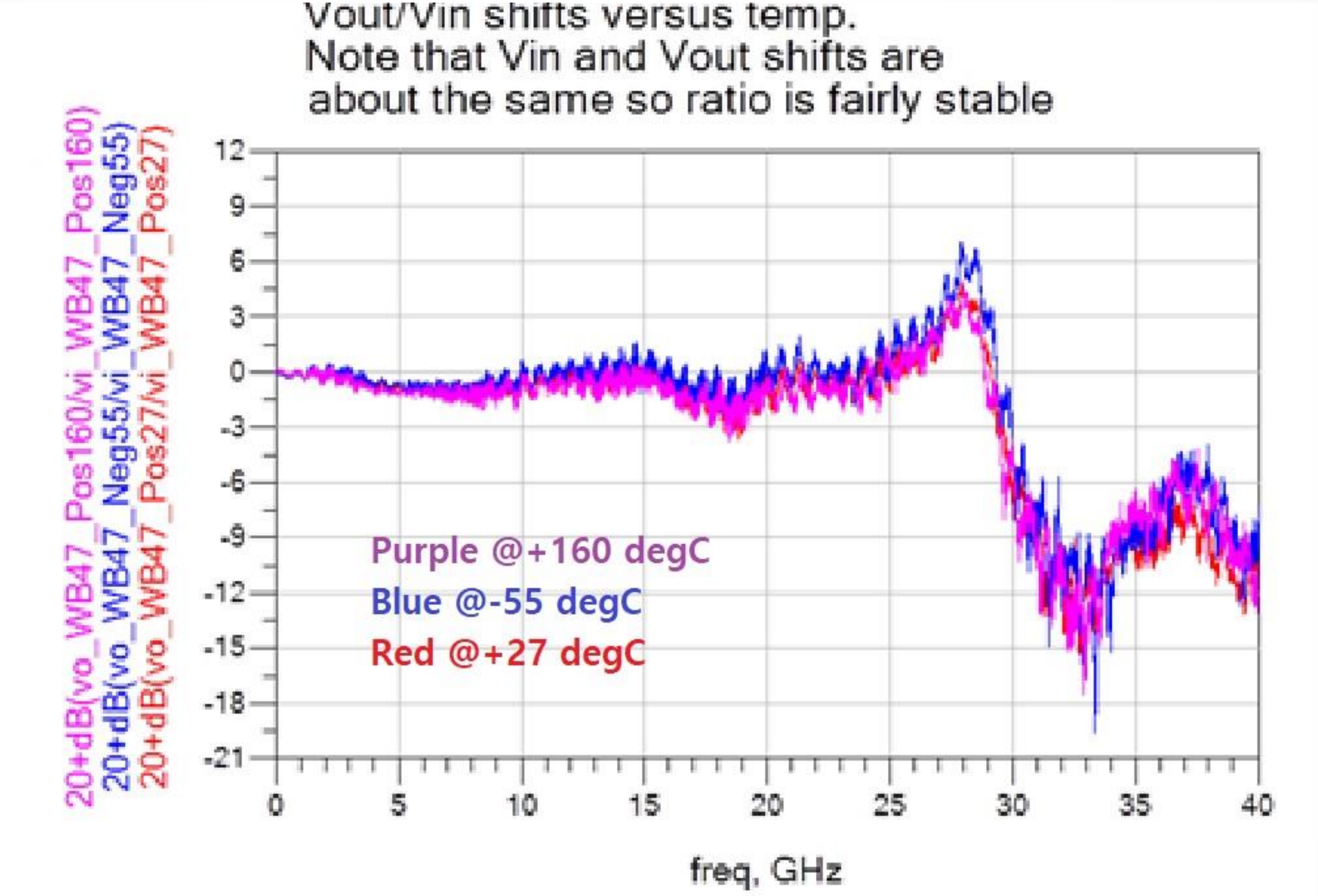
MX0109A frequency response variations over temp

Vout/Vin variation over +160 to -55 degC temperature is fairly small



Summary

- Probe tip accessories can greatly affect the overall performance of the probing system. If at all possible, keep the input leads of the probe tip and the loop area of connection as small as possible.

- If a probe has significant signal content beyond its stated bandwidth, the PrecisionProbe can extend the bandwidth of the probe, flatten the response and enhance its usefulness.

- There are two types of loading characteristics for probes – RC vs RCRC profiles. Know when to choose RC vs RCRC probe.

- Choose a probe with lower attenuation ratio to achieve higher signal-to-noise ratio.

- Use probe offset to look at small signal riding on top of big DC signal.

- Keysight provides industry's most comprehensive extreme temperature probing solutions. www.keysight.com/find/extreme

Keysight Probe Application Notes

Document #	Application Note Title
5988-6515EN	The Truth About the Fidelity of High-Bandwidth Voltage Probes
5988-8005EN	Improving Usability and Performance in High-Bandwidth Active Oscilloscope Probes
5988-8006EN	Performance Comparison of Differential and Single-ended Active Voltage Probes
5988-9264EN	Understanding and Using Offset in InfiniiMax Active Probes
5989-7587EN	Extending the range of Keysight InfiniiMax Probes
5992-0694EN	Demystifying RCRC and RC Probes
5992-2975EN	Bandwidth boosting techniques for InfiniiMax probes
5992-3350EN	Probe soldering guidelines for Keysight InfiniiMax probes

Enter document # in search box at www.keysight.com/find/probes


Thanks.